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Physics Procedia 70 (2015) 905 – 908

Physics Procedia

2015 International Congress on Ultrasonics, 2015 ICU Metz

Evaluation of mechanical losses in piezoelectric plates using genetic algorithm

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Abstract

Numerical methods are used for the characterization of piezoelectric ceramics. A procedure based on genetic algorithm is applied to find the physical coefficients and mechanical losses. The coefficients are estimated from a minimum scoring of cost function. Electric impedances are calculated from Mason's model including mechanical losses constant and dependent on frequency as a linear function. The results show that the electric impedance percentage error in the investigated interval of frequencies decreases when mechanical losses depending on frequency are inserted in the model. A more accurate characterization of the piezoelectric ceramics mechanical losses should be considered as frequency dependent.

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Keywords:Piezoelectricity; characterization of ceramics;losses; evolutive algorithm; mechanical.

1. Introduction

The characterization of piezoelectric ceramics is a fundamental step in the design of ultrasonic transducers. Experimental and numerical methods have been used to estimate piezoelectric parameters of devices in order to know their physical properties and to optimize transducers design. In general, the methodology neglects the losses. Nevertheless, when losses are larger, deviations between experimental and theoretical results can become meaningful. For this reason, the procedure shown in ANSI/IEEE (1987) is not suitable to obtain accurate results.

Losses are inserted in physical models as constant values represented by complex numbers (Holland, 1967). Experimental determination of losses has a sensible procedure, not always easy to accomplish. On the other hand, numerical methods are a good option to determine the parameters for the characterization of the lossy piezoelectric ceramic. Approaches based on fitting of experimental data using numerical methods are found in the literature cited by Kwok et al. (1997), El-Nachef et al. (1992), Sherrit et al. (1992), Alemany et al. (1994), Pérez et al. (2010), Gonzalez et al. (1996), Ruiz et al. (2004). This work presents a numerical approach to estimate physical parameters of piezoelectric ceramics considering mechanical losses. An expression of electric impedance for thickness mode

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doi:10.1016/j.phpro.2015.08.187

vibration of the ceramic including mechanical losses constitutes the physical model. A computer program, based on genetic algorithms, has been implemented to find optimized physical parameters when the mean square error (*MSE*) between experimental and computed values is minimum. *MSE*s from simulated data of lossless and lossy models have been determined. Mechanical losses have been considered dependent on frequency and inserted in the model.

2. Theory

In ANSI/IEEE (1987) is presented the electric impedance for a lossless piezoelectric plate vibrating on thickness mode. Considering the mechanical losses in this model, for lossy piezoelectric materials, the impedance is given by Eq. (1):

$$Z(\omega) = \frac{1}{j\omega C_0}\left(1 - k^{*2}\,\frac{\tan\left(\frac{\omega\pi t}{2}\left(\frac{\rho}{c_{33}^D(1+j\tan(\delta_m))}\right)^{1/2}\right)}{\frac{\omega\pi t}{2}\left(\frac{\rho}{c_{33}^D(1+j\tan(\delta_m))}\right)^{1/2}}\right) \tag{1}$$

where ω is the angular frequency (rad/s); $C_0=\varepsilon_{33}{}^S A/t$ is the clamped (S=0) capacitance of the piezoelectric ceramic (F); $\varepsilon_{33}{}^S$ is the dielectric permittivity (F/m); $A=\pi r^2$ is the area of the electrodes (m^2); r is the radius (m); t is the thickness (m); $k^*=k/(1+j\tan(\delta_m))^{1/2}$ is the electromechanical coupling factor; k is the electromechanical coupling factor for the lossless characterization; ρ is the density of the material; $c_{33}{}^D$ is the elastic coefficient (N/m^2); $\tan(\delta_m)$ is the mechanical loss tangent.

In the problem studied in this paper, a software based on genetic algorithm plays a role for finding an optimized set of parameters for achieving a minimum of a cost function. The set of parameters is composed of $c_{33}{}^D$, $\varepsilon_{33}{}^S$, k and $\tan(\delta_m)$. The cost function (Eq. 2) is the mean square error (*MSE*) between simulated and experimental data.

$$MSE = \sqrt{\frac{\sum_{i=1}^{N}\left(\left(R_m - R_{\exp}\right)^2 + \left(X_m - X_{\exp}\right)^2\right)}{N}} \tag{2}$$

where R_m and X_m are the real and imaginary components from Eq. 1; R_{exp} and X_{exp} are the real and imaginary components from experimental data; N is the size of the sample of frequencies.

3. Materials and Methods

The ceramic used in the experiment is disk-shaped made by Ferroperm - Denmark. The electrodes are coated on each flat surface. In this ceramic, radius is r = 3.17 mm, thickness is t = 2.0 mm and density is ρ = 7750 kg/cm3. The frequency spectra of the piezoelectric ceramics have been determined with an impedance analyzer HP4294A. The thickness of the ceramic and the typical values of physical properties of PZT and similar, allows us to estimate approximated value for the resonance of the thickness mode. Only one pair resonance-antiresonance is regarded for the computation.

The genetic algorithm was run with size population of 500, number of generations of 500, crossover rate of 90% and mutation probability of 10%.

4. Results and discussion

The results are presented in frequency spectra and percentage error rate for lossy and lossless ($\tan(\delta_m) = 0$) models as function of frequency. Figs. 1a and 1b show electric impedance modulus and error rate of the piezoelectric disk. The parameters calculated by computer program are: = 16.2215×10^{10} N/m^2; k = 0.2650; $\varepsilon_{33}{}^S$ = 4.48×10^{-9} F/m and $\tan(\delta_m) = 5.5078\times10^{-3}$. The percentage error rate average is 14.0586% and 82.2269% for lossy and lossless simulated data.

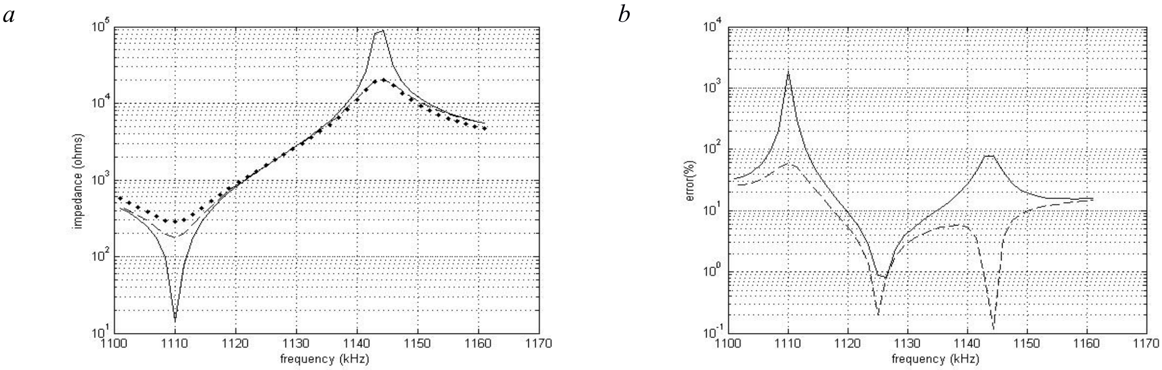

Fig. 1. (a) Electric impedance as function of frequencies. Dotted, dashed and continuous lines represent experimental, lossy and lossless simulated data, respectively; (b) Percentage error rate as function of frequencies. Dashed and continuous lines represent the errors for lossy and lossless simulated data, respectively.

Fig. 1a shows an excellent fitting of experimental data with simulated ones from lossy model at vicinity of antiresonance. We have found that the fitting accuracy becomes better near at resonance and worse at antiresonance, when simulations with incrementation of $\tan(\delta_m)$ are run. This means that mechanical losses vary with frequency. So, we have suggested the model (Eq. 1) according to Eq. 3

$$\tan(\delta_m) = -\alpha f + \beta \tag{3}$$

where α and β are determined by proposed algorithm. We have calculated $\alpha = -1.166\times10^{-7}$ and $\beta = 0.1391$.

Figs. 2a and 2b show electric impedance modulus and error rate of the piezoelectric disk regarding $\tan(\delta_m)$ according to Eq. 3. The average percentage error with correction is 5.3562%. Thus, the insertion of frequency dependence on mechanical losses has improved the fitting accuracy. The mechanical loss is higher at resonance than at antiresonance, because velocity vibration and friction should be proportional.

The frequency spectra of other transducers have been investigated too. Simulations show that calculated errors from lossy model are inferior to lossless ones. The generalization of Eq. 3 allows us to investigate the behavior of the mechanical losses as function of frequency at an interest range. The dependence of frequency on mechanical losses is recommended for the more accurate characterization of piezoelectric ceramics.

a *b*

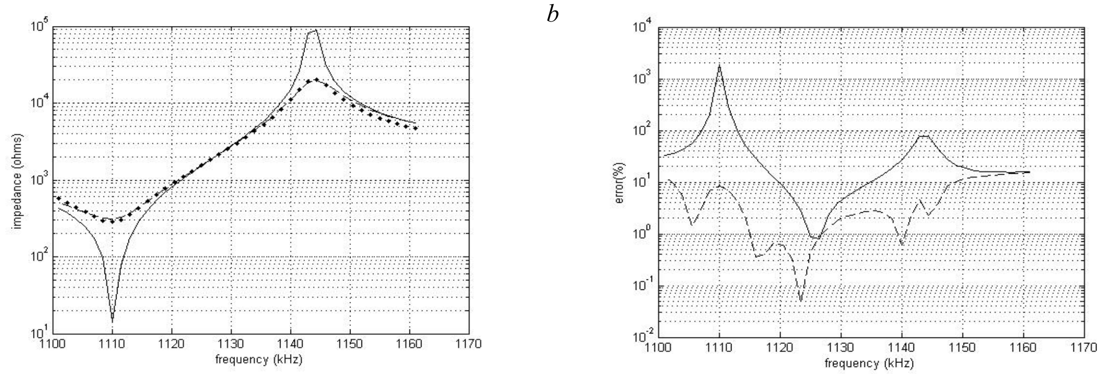

Fig. 2. (a) Electric impedance as function of frequencies. Dotted, dashed and continuous lines represent experimental, lossy and lossless simulated data, respectively. Results corrected according to Eq. 3.; (b) Percentage error rate as function of frequencies. Dashed and continuous lines represent the errors for lossy and lossless simulated data, respectively. Results corrected according to Eq. 3.

5. Conclusion

Piezoelectric plates have been characterized regarding mechanical losses dependent on frequency. The results obtained with the new physical model are best fitted to the experimental data than those obtained with modeling using losses as a constant value.

Acknowledgements

Authors are grateful to FAPESP (Proc. 2012/07639-4, 2011/12792-3).

References

ANSI/IEEE, 1987. Standard on Piezoelectricity 176.

Alemany, C., Pardo, L., Jiménez, B., Carmona, F., Mendiola, J., Gonzalez, A., 1994. Automatic iterative evaluation of complex material constants in piezoelectric ceramics, Journal of Physics D 27, 148-155.

El Nachef, S., Brissaud, M., Noterman, D., 1992. Limitations du modèle de Mason pour l'identification des parameters complexes des céramicques piézoélectriques, Acustica 76, 209-223.

Gonzalez, A., Alemany, C., 1996. Determination of the frequency dependence of characteristic constants in lossy piezoelectric materials, Journal of Physics D 29, 2476-2482.

Holland, R., 1967. Representation of dielectric, elastic and piezoelectric losses by complex coefficients, IEEE Transactions on Sonic and Ultrasonics l4, 18-20.

Kwok, K.,Chan, H., Choy, C., 1997. Evaluation of the Material Parameters of Piezoelectric Materials by Various Methods, IEEE on Transactions on Ultrasonics, Ferroelectrics and Frequency Control 44, 733-742.

Pérez, N., Andrade, M., Buiochi, F., Adamowski, J., 2010. Identification of Elastic, Dielectric, and Piezoelectric Constants in Piezoceramic Disks, IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control 57(12), 2772-2783.

Ruiz, A., San Emeterio, J., Ramos, A., 2004. Evaluation of Piezoelectric Resonator Parameters using an Artificial Intelligence Technique, Integrated Ferroelectrics 63, 137-141.

Sherrit, S., Wiederick, H., Mukherjee, B., 1992. Non-interative evaluation of the real and imaginary material constants of piezoelectric resonantors, Ferroelectrics 134, 111-119.